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Idaho National Engineering and Environmental Laboratory

Stellite 6 Friction Changes Due To Aging And In-Service Testing

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STELLITE 6 FRICTION CHANGES DUE TO AGING AND IN-SERVICE TESTING[1]

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ABSTRACT

For the past several years, researchers at the Idaho National Engineering and Environmental Laboratory, under the sponsorship of the U.S. Nuclear Regulatory Commission, have been investigating the ability of motor-operated valves to close or open when subjected to design basis flow and pressure loads. Part of this research addresses the friction that occurs at the interface between the valve disc and the valve body seats during operation of a gate valve. In most gate valves, these surfaces are hardfaced with Stellite 6, a cobalt-based alloy.

The nuclear industry has developed methods to analytically predict the thrust needed to operate these valves at specific pressure conditions. To produce accurate valve thrust predictions; the analyst must have a reasonably accurate, though conservative, estimate of the coefficient of friction at the disc-to-seat interface. One of the questions that remains to be answered is whether, and to what extent, aging of the disc and seat surfaces affects the disc-to-seat coefficient of friction. Specifically, does the accumulation of a surface film due to aging of these surfaces increase the coefficient of friction and if so, how much?

This paper presents results of specimen tests addressing this issue with emphasis on the following:

- The change in the friction coefficient of Stellite 6 as it ages and whether the friction reaches a plateau.
- The effect periodic gate valve cycling due to in-service testing has on the friction coefficient.
- The results of an independent review of the test methods, processes, and the results of the research to date.
- The status of ongoing aging and friction testing.

INTRODUCTION

The Idaho National Engineering and Environmental Laboratory (INEEL) has been investigating the ability of motor-operated valves (MOVs) to function when subjected to design basis loads. Methods exist to analytically predict the thrust needed to operate these valves at specific fluid conditions; however, the analyst must have a reasonably accurate, though conservative, estimate of the coefficient of friction at the disc-to-seat interface (see Fig. 1). In most gate valves, these surfaces are hardfaced with Stellite 6, a cobalt-based alloy. One of the questions that has not been addressed is whether, and to what extent, aging of the disc and seat surfaces affects the disc-to-seat coefficient of friction. Specifically, does the accumulation of an oxide film on these surfaces during long term operation in harsh environments increase the coefficient of friction; and if so, how much?

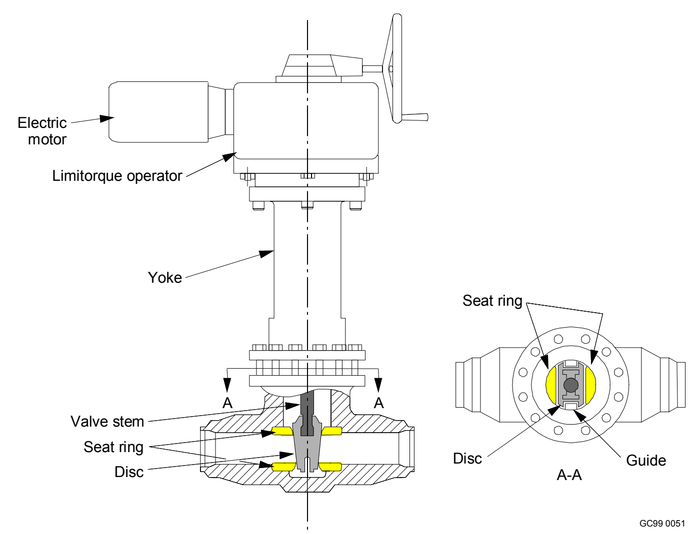

Figure 1. Diagram of a typical motor-operated gate valve showing the main components.

[1] Work performed under U. S. Department of Energy Contract No. DE-AC07-99ID13727.

This paper presents the latest results from an ongoing INEEL research project addressing this issue. The purpose of this project is to determine how aging degradation mechanisms can affect the performance requirements of MOVs over the long term. The results of this project will provide information on the coefficient of friction expected of a fully aged valve, including the effect of periodic valve cycling typical of in-service tests. The results will also be used to assess an ongoing industry periodic verification-testing program. The industry testing is designed to determine whether aging of the valve surfaces will affect the operability of an MOV.

The project consisted of subjecting Stellite 6 specimens to an environment simulating boiling water reactor (BWR) coolant conditions, representing the conditions a typical reactor water clean-up (RWCU) isolation valve would experience, and inducing the accumulation of an oxide film. The project included analysis of the resulting oxide film and testing of the specimens to determine the coefficient of friction. The Battelle Memorial Institute in Columbus, Ohio performed the testing under a contract with the INEEL and the National Institute of Standards and Technology (NIST) has performed a critical review of the test methods, processes, and the results of the research to date.

TEST PROGRAM

This paper describes the results of two types of aging tests, both dealing with Stellite 6. The first investigated natural aging at simulated BWR conditions. For these tests, we determined the oxide film thickness and composition following 2-, 10-, 20-, 25-, 40-, 50-, and 78-day exposure periods to BWR conditions simulated in a corrosion autoclave. We performed friction testing on specimens after 2, 10, 20, 40, and 78-days exposure. The second test type also investigated natural aging but included the effect of periodic cycling on the valve oxide films. The purpose of these later tests was to determine whether the film composition and friction coefficient are influenced by the periodic disc wedging encountered during in-service testing (IST). For these tests, we determined the oxide film composition both before and after the simulated valve wedging after 25 days and again after 50 days in the corrosion autoclave. Friction testing was performed after 78 days in the corrosion autoclave.

The specimens were naturally aged at simulated BWR coolant conditions in a corrosion autoclave. To simulate BWR coolant conditions, the autoclave was attached to a reservoir of water in which the oxygen was controlled in the range of 100 to 200 ppb. Water from the reservoir was continuously supplied to the autoclave, with the temperature in the autoclave maintained at 550°F, and the pressure at 1050 psi, slightly above the saturated steam pressure, such that the water was slightly subcooled.

We used a friction autoclave to perform the friction tests. The friction autoclave, like the corrosion autoclave, was attached to a reservoir of water in which the oxygen was controlled in the range of 100 to 200 ppb. Testing was performed with the autoclave heated to 550°F and pressurized to about 1050 psi. During each test, a specimen assembly consisting of two smaller 0.25-in. x 1.10-in. outer specimens and two larger 0.5-in. x 3.0-in. inner specimens was tested (see Fig. 2). The outer specimens were held in a stationary fixture, and the inner specimens were attached to a carrier bar connected to a movable pull rod. Actuation of the pull rod caused the inner specimens to slide along the outer specimens at a relative velocity of approximately 16 in./min, a rate within the range expected for typical gate valve operation.

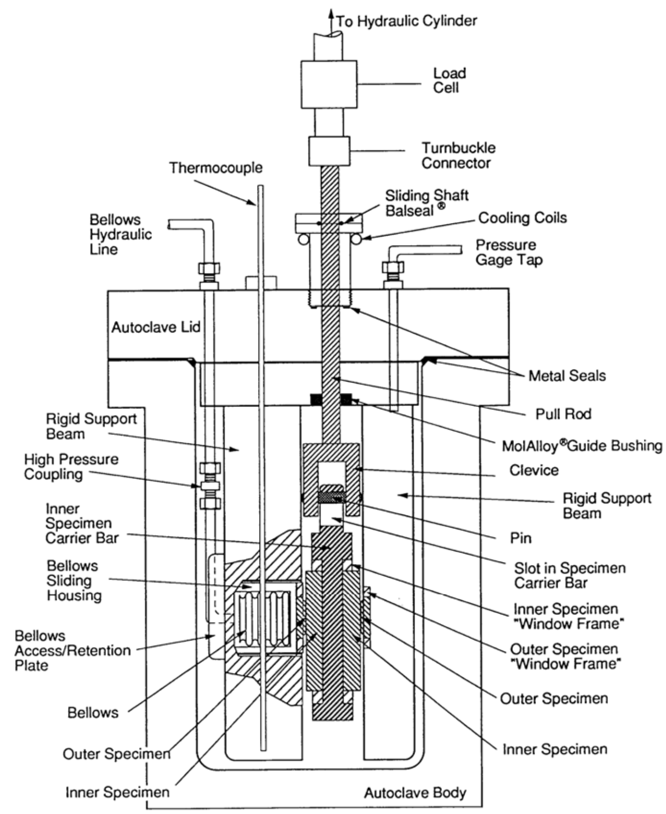

Figure 2. Diagram of the friction autoclave.

The friction autoclave is equipped with a bellows that can exert a force on one side of the specimen assembly. Pressurizing the bellows imposes a normal force on the specimens to produce the specified nominal contact stress of 10 ksi. The normal force required to achieve a 10-ksi nominal contact stress on the 0.25-in. x 1.10-in. contact zone is 2750 lb. This value was selected to approximate the stress level occurring during operation of typical RWCU system valves. (Assuming uniform load distribution, the calculated contact stresses at the seats for typical 4 and 6-in. valves under a differential pressure of 1,050 psi are 7.8 and 12.6 ksi, respectively.)

For the simulated valve wedging representing IST cycling, we used an in-service testing simulation rig. Unlike conditions in both the corrosion autoclave and the friction autoclave, conditions in the in-service testing simulation rig consisted of a water bath at room temperature and atmospheric pressure rather than simulated BWR coolant conditions. To subject the entire surface of each specimen to a simulated valve wedging, we placed like sized specimens with their Stellite 6 surfaces face to face, applied a normal load of 20 ksi, and moved the specimens 0.040 in. relative to each other. We selected a stress level of 20 ksi to approximate the bearing stress occurring during a valve wedging cycle of a typical RWCU system valve. The 0.040 in. displacement is based on the approximate distance the

Stellite 6 surfaces on the disc and the seat would move relative to each other during valve wedging for a typical RWCU system valve. We considered using the high temperature friction autoclave for the simulated cycling, but it could not achieve the required contact stress on the larger 0.5-in. x 3.0-in. specimens. A normal load of 30,000 lb was required, well in excess of the capabilities of the friction autoclave.

FILM CHARACTERIZATION

The chemical composition of the oxide films was analyzed by Auger electron spectroscopy (AES) for some specimens and by X-ray photoelectron spectroscopy (XPS) for others (and both methods for a few specimens). With AES and XPS, the film is incrementally sputtered away, and the elemental compositions of planes in the oxide film are measured. The results of these analyses are then plotted versus time (or depth, assuming a sputtering rate) to provide a depth profile so that the relative elemental concentrations can be evaluated. Fig. 3 shows a typical AES depth profile for Stellite 6 after exposure to natural aging conditions. As can be seen from the plot, the chromium concentration is almost constant through the oxide film, whereas the cobalt is lean at the surface and rapidly rises between 1000 and 2000 Å. [One Angstrom (Å) equals one ten-millionth of a millimeter.]

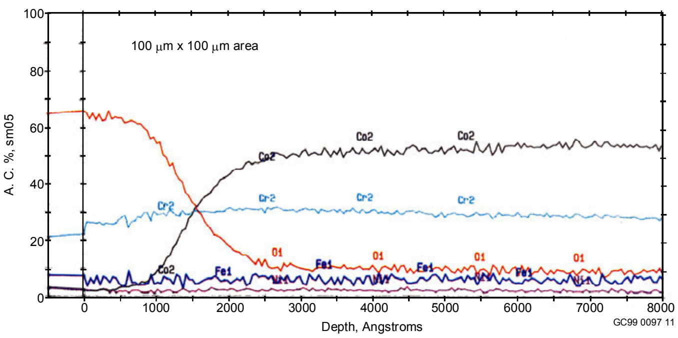

Figure 3. AES depth profile for Stellite 6 after 20 days exposure to natural aging conditions.

The composition of the oxide file was similar to that observed by other researchers [1, 2] for Stellite 6 specimens exposed to lithiated high temperature water. The results show that the surface of the oxide film is rich in chromium and lean in cobalt.

As part of the critical review of this research, NIST also analyzed the oxide film of 10 day and 50-day specimens using Atomic Force Microscope (AFM) and X-ray diffraction. NIST concluded that the oxide film contains crystalline solids within an amorphous substrate. These crystalline solids could be chromium oxides, cobalt oxides, and/or carbides. Crystalline solids are, in general, very abrasive and can result in high friction between moving surfaces.

FRICTION TESTING

Five sets of naturally aged specimens underwent friction tests. The aging times for these specimen sets were 2, 10, 20, 40, and 78 days. This testing showed that the coefficient of friction continually increased as the specimens aged and as the film thickness increased. In fact, Fig. 4 indicates that the friction not only increases as the specimens age, but that it does not appear to reach a plateau. These results question whether the friction coefficient and the film thickness will reach stable values as the specimens continue to age. This information is important, because as the friction increases, the thrust demands of a valve will increase and influence the available operating margin of the MOV. The friction tests were performed with the specimens in an autoclave at 550°F and 1050 psi. As such, the continuously increasing friction is the result of the oxide thickness increasing and is not due to the preconditioning phenomenon that is encountered when friction testing is performed on specimens in an ambient environment.

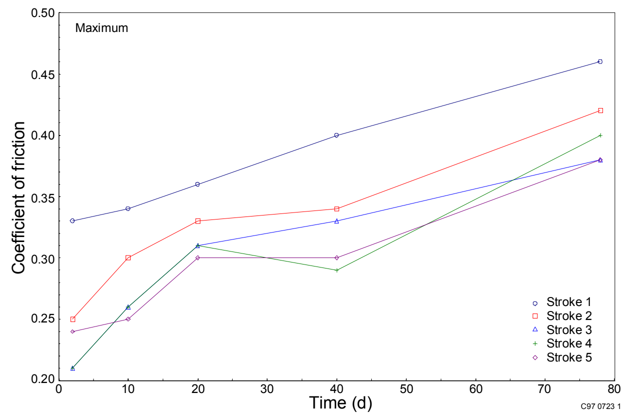

Figure 4. Coefficient of friction versus time for naturally aged Stellite 6 specimens; maximum values (top) and nominal values (bottom).

Fig. 5 presents the same friction information in a different format to show how the coefficient of friction responds to continued stroking of the same specimen. The results show that the friction is highest during the first stroke and decreases with each subsequent stroke. Even though additional stroking of the specimens decreases the friction, the friction generally increased as the specimen aged. This continual increase in friction over time indicates the importance of trending the valve friction over time. The data also shows that the highest friction occurs during the first stroke and decreases with each subsequent stroke. The first stroke a valve experiences after it has been allowed to age and establish an oxide film will result in the highest coefficient of friction and therefore require the highest stem thrust to overcome these friction forces.

The increase in friction as the specimen ages is due to the mechanical properties of the films (oxides and hydroxides) developed during aging. As the oxide film develops, the friction coefficient would be expected to approach that which might be measured using specimens of the same composition as the oxide film, i.e., solid oxide specimens. Oxides typically have higher friction coefficients than their metal counterparts. However, for the natural aging cases investigated thus far, the oxide films were extremely thin. It is most likely that under the relatively high contact stresses of the experiments (10 ksi), these oxide films were immediately ruptured upon the onset of sliding and subsequently were mixed into the substrate surface. This is typical behavior of a thin hard coating (such as the oxide film of Stellite 6) on a relatively softer substrate.

As such, the friction coefficient represents a mixture of the friction of the bulk Stellite 6 material and the friction of the oxide film.

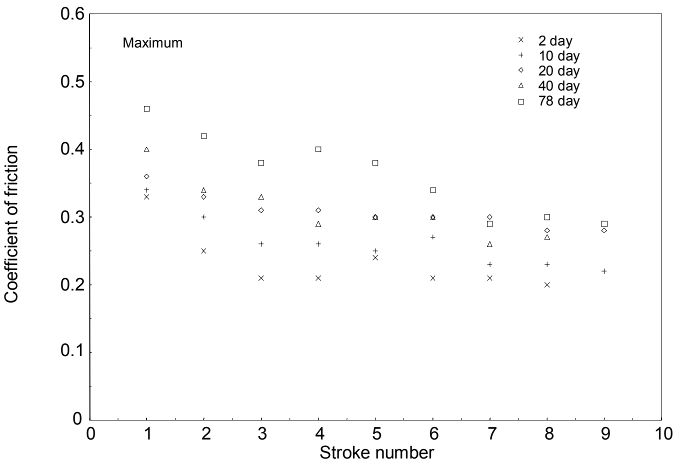

Figure 5. Coefficient of friction versus stroke for Stellite 6 specimens exposed to natural aging conditions; maximum values (top) and nominal values (bottom).

NIST reviewed the friction testing and was concerned with the testing simulating the actual operation of a valve. As tested, the full surface is initially in contact and the hard corrosion products are trapped between the surfaces. NIST noted that during actual valve operation, the moving surfaces may come into contact and push the corrosion products out of the way without being trapped. To investigate these concerns, selected Stellite 6 specimens were friction tested at NIST. 10 day and 50 day specimens were tested but the testing was performed at ambient temperature and pressure. Two types of friction tests were performed. One test configuration pushed the corrosion products out of the way and a friction between 0.15 and 0.17 was observed. The other test configuration trapped the corrosion products and a friction between 0.30 and 0.35 was observed. The latter configuration was comparable to the results of friction testing similar specimens in the autoclave, 0.35 to 0.40.

One set of specimens subject to natural aging conditions and simulated IST valve wedging cycles underwent friction tests. The aging time for these specimens was 78 days, with simulated valve wedging cycles after 25 days and again after 50 days. Fig. 6 presents the results of this testing and shows that specimens that were subjected to simulated valve wedging cycles had a lower coefficient of friction, although it is not clear whether this trend will continue as the specimens age. During subsequent strokes, the effect of the simulated valve wedging on the resulting friction coefficient was either negligible or varied from stroke to stroke. This frictional behavior is influenced by changes in the condition of the surface due to previous strokes. As such, only the first stroke would be strongly influenced by the simulated valve wedging.

RECOMMENDATIONS FROM NIST

NIST recommended that additional friction testing should start from a non-contacting position similar to the operation of a valve and that further studies should be performed with more samples to verify the results. Based on these recommendations, we are preparing to age specimens at simulated BWR conditions for 0, 30, 60, 90, and 120 days. The specimens will then be friction tested to simulate both full surface contact with the corrosion products trapped between the surfaces and two moving surfaces coming into contact and pushing the corrosion products out of the way without being trapped.

Testing and data evaluation is scheduled for completion by the end of 2001.

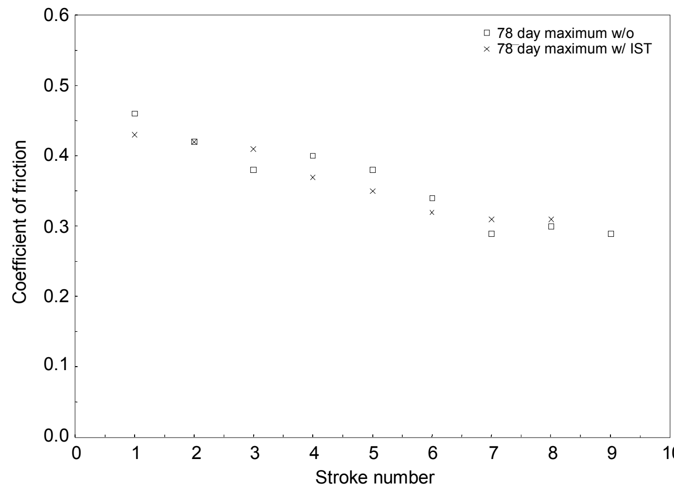

Figure 6. Maximum coefficient of friction versus stroke for naturally aged Stellite 6 specimens and specimens subject to in-service testing.

CONCLUSIONS

This paper presents the latest results of an ongoing INEEL research project addressing the aging of Stellite 6 specimens at simulated BWR conditions. This project identified a number of trends in the frictional characteristics of Stellite 6 that may influence the available operator margin of a MOV as it ages. These trends are summarized below.

The friction of the naturally aged specimens shows a continual increase as the aging time increases, with no evidence of reaching a plateau after 78 days of aging. This information is important because as the friction increases, the thrust demands of a valve will also increase and influence the available operating margin of the MOV.

The friction is highest during the first stroke and decreases with additional stroking. This continual increase in friction over time indicates the importance of trending the valve friction over time. The data also show that the highest friction occurs during the first stroke and decreases with each subsequent stroke. The first stroke a valve experiences after it has been allowed to age and establish an oxide film will result in the highest coefficient of friction and therefore will require the highest stem thrust to successfully operate the valve.

The single data point for the periodic valve wedging test suggests that periodic disc wedging will decrease the expected friction compared to a valve that is less frequently cycled. Although there is only a single data point and the effects of the IST cycle may be small for this case, the data suggest that increasing the time between IST cycling may allow the friction to increase enough to impact the available operating margin of an MOV.

Additional testing is underway. We are currently machining new test specimens and corrosion and friction testing is scheduled for completion by the end of 2001.

REFERENCES

1. Hocking, W. H. and Lister, D. H., Corrosion of Stellite-6 in Lithiated and Borated High-temperature Water, Surface and Interface Analysis, 1988.
2. Hocking, W. H., et al., Mechanisms of Corrosion of Stellite-6 in Lithiated High Temperature Water, Corrosion Science, Vol 25, No. 7, pp 531-557, 1985.

NOTICE